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ADAPTATION, TELEOLOGY, AND SELECTION BY CONSEQUENCES

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This paper presents and defends the view that reinforcement and natural selection are selection processes, that selection processes are neither mechanistic nor teleological, and that mentalistic and vitalistic processes are teleological but not mechanistic. The differences between these types of processes are described and used in discussing the conceptual and methodological significance of "selection type theories" and B. F. Skinner's radical behaviorist view that "operant behavior is the field of intention, purpose, and expectation. It deals with that field precisely as the theory of evolution has dealt with another kind of purpose" (1986, p. 716). The antimentalism of radical behaviorism emerges as a post-Darwinian extension of Francis Bacon's (and Galileo's) influential view that "[the introduction of final causes] rather corrupts than advances the sciences" (Bacon, 1905, p. 302).

Key words: reinforcement, natural selection, mechanism, mentalism, scientific explanation, causation, teleology

The aim of this paper is to discuss two arguments. The first argument is that there is a significant parallel between natural selection and reinforcement (or operant conditioning). The second is B. F. Skinner's argument that this parallel shows what is problematic about cognitivism and what is promising about radical behaviorism. A proposed interpretation suggests that the two arguments challenge conventional wisdom concerning the nature and relative plausibility of contemporary behaviorist and cognitivist programs for scientific psychology: The antimentalism of radical behaviorism is an expression of the modern natural-science tradition of rejecting the Aristotelean doctrine of final causation. Mentalism and the forms of cognitivism that endorse mentalism are a return to the Aristotelean doctrine. The issues at stake are post-Darwinian versions of those posed by Francis Bacon's (1905) maxim that "[the introduction of final causes] rather corrupts than advances the sciences except such as have to do with human action" (p. 302).

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THE ARGUMENTS

Terry Smith (1983) provides a succinct version of the argument that natural selection and reinforcement are analogous processes. He asserts:

> To state the analogy baldly: Natural selection is to the origin of species as operant conditioning is to the origin of behavior. Just as the members of a population of organisms exhibit variation, and the environmental consequences of each variation play a role in determining the probability that given individuals will reproduce, and thus influence the probability that a given organic variety will reoccur, so likewise do the actions composing a population of operants of an individual organism exhibit variation, and the environmental consequences of each variation play a role in determining the probability that given operants will be reinforced, and thus influence the probability that a given behavioral variety will reoccur. Thus, organic and behavioral types are selected by environmental "fit," and in both cases an instance of a given type is explained on the basis of the environmental consequences that accompanied prior instances of that type. (p. 136)

Skinner often (e.g., 1969, 1981) alluded to such an analogy in defending his claim that both operant conditioning and natural selection exhibit a distinctive causal mode that he termed *selection by consequences*. Skinner took this similarity to highlight both what is problematic about cognitivist approaches to scientific psychology and what is distinctive about radical behaviorist alternatives to cognitivism. This

feature of Skinner's argument will be the main topic of this paper.

Skinner (1969) suggested that there is a lesson to be learned from the history of biology. Like many cognitivists, Skinner described "issues which define behaviorism" as issues concerning "the usefulness of mentalistic concepts" (p. 267). He also granted that "the physiological processes which mediate behavior do not, so far as we know, differ from those involved in other functions of a living organism" (pp. 283–284). Skinner, however, asserted that "Behavior is . . . a field which can be successfully analyzed apart from the world of mind." Against this background, Skinner proposed an analogy: "the activities which testify to the presence of Mind are simply part of those which testify to the presence of Life." He argues, "biology . . . has lost its Life and just as biology has never been livelier, so psychology has never been more keenly aware of its problems or of the steps to be taken in finding solutions" (p. 297). In Skinner's view, these benefits accrue to psychology as a result of psychology losing its Mind. Thus, mentalism in psychology is a modern manifestation of a type of research program that historically has proved to be scientifically abortive. Specifically, Skinner treated vitalism and mentalism as programs of the same stripe. Viewing psychology as a branch of biology, Skinner presented the failure of vitalism in biology as a lesson for psychology that has been validated by the recent history of the experimental analysis of behavior. According to Skinner, vitalistic explanations of organic structure and development are related to explanations in terms of natural selection (and relevant biochemical processes) in the same way that mentalistic explanations of behavior are related to explanations in terms of operant conditioning (and relevant physiological processes). Skinner suggested that in light of these analogies, the success of Darwinism and the demise of vitalism in scientific biology provide a lesson for scientific psychology: Mentalism, like vitalism, is a scientific cul de sac. Contingencies of reinforcement, like contingencies of survival, offer a distinct and promising area to explore. Thus, Skinner presented a defense of radical behaviorism and a critique of mentalism in scientific psychology.

This argument expresses themes in Skinner's work that have emerged with increasing explicitness since his first (1937) formulation of the distinctions between operant and respondent conditioning. Skinner asserted that selection by consequences is different both from the type of mechanistic causal processes that are described in theories of the type inspired by Newtonian (classical) mechanics (e.g., the processes of stimulus–response association described in the types of theories inspired by Pavlov, 1927, and Clark Hull, 1930) and the type of mentalistic processes described in common-sense accounts of the decisions and actions of rational agents. In Skinner's view, Darwin's crucial methodological innovation was to suggest a new (i.e., nonmechanistic) way of explaining function, goal direction, and adaptation without appeal to intelligent agency or the mentalistic concepts that such appeals suggest. Natural selection provides a model that can guide construction of explanations of how adaptedness comes about in the behavioral realm.

This special issue of *JEAB* provides a timely occasion to reflect on the nature and significance of Skinner's view. In contemporary cognitive science, the mentalism of classical cognitivism is no longer unchallenged dogma (Churchland & Sejnowski, 1992). The role of selection processes in cognitive development (Edelman, 1992) is being closely examined. Recent investigations (L. Smith, 1986) demonstrate that widely accepted views of the nature of behaviorism are mistaken in ways that undermine influential assessments of the relative merits of behaviorism and classical cognitivism (Ringen, 1976, 1993a). Skinner's view provides the materials for a description of behaviorism and its relations to classical cognitivism that depends both on the nature of reinforcement and the nature of selection processes. This view is a strong candidate for replacing the mistaken traditional view, and it deserves to be carefully articulated and seriously examined. What follows is the beginning of that task.

ADAPTATION, SELECTION, AND OPTIMIZATION

Whether there is merit in Skinner's arguments depends not only on the defensibility of the analogies he deploys but also on the general significance of analogies in the assessment of scientific research programs and practices, such

as the construction of theories of specific types. There is reason to think that Skinner's arguments have considerable merit, even though his conclusions are in conflict with widely influential contemporary descriptions and assessments of behaviorism.

Skinner's general way of arguing seems to be in accord with an influential post-Kuhnian consensus (e.g., Darden & Cain 1989; D. Hull, 1988; Kuhn, 1962; Lakatos, 1978; Laudan, 1977) that the past success of similar scientific practices in treating similar problems is pertinent to the assessment of the relative promise of currently competing programs. Furthermore, there is emerging consensus that certain of Skinner's analogies do fit both his own work and the work of Darwin.

Although one can find occasional dissent (e.g., Sohn, 1976), the literature (e.g., Catania, 1987; Darden, 1983; Ghiselin, 1969; Ringen, 1986; T. Smith, 1983; Staddon, 1979, 1983) exhibits considerable agreement about the positive analogy between the processes of operant conditioning and natural selection and between the phenomena these processes are invoked to explain, namely behavioral and phenotypic adaptedness, respectively. Furthermore, in spite of a persistent tendency to describe radical behaviorism as mechanistic and as a version of stimulus–response (S–R) associationism (e.g., Mahoney, 1989), there is an emerging consensus that selection processes exhibit distinctive characteristics that both radical behaviorism and evolutionary biology emphasize. Specifically, radical behaviorism and evolutionary biology share an emphasis on the selective action of the environment rather than on the proximate causation of behavioral or biological variations on which selection processes operate (Mayr, 1961, 1976; Skinner, 1977, 1981; Sober, 1983, 1985; Staddon, 1983). Finally, studies of Skinner's work (Coleman, 1981, 1984) indicate that after an initial period influenced by an explicitly mechanistic conception of reflexes, Skinner began to develop and articulate a conception of operant conditioning in which the analogies with natural selection were made increasingly explicit and disanalogies with mechanistic and mentalistic views increasingly emphasized. What remains most controversial is what the significant features of these disanalogies are.

In the *Origin of Species* as well as the earlier essays on which the *Origin* was based, Darwin (1909, 1923) presented natural selection by way of an analogy with artificial selection; the deliberate actions of rational human agents in facilitating the reproduction of organisms exhibiting certain specified characteristics and inhibiting the reproduction of others. Darwin's analogy exhibits both positive and negative components. He emphasized the positive analogy, that both under cultivation and domestication and in the wild, selection determined the relative likelihood of reproduction of organisms exhibiting naturally occurring variations of characteristics. This positive analogy has strongly influenced modern biology. There is, however, a problem implicit in Darwin's analogy that has resisted solution.

The general problem is that natural selection is a process that does not involve intelligent choice and design but produces similar results. In natural selection, unlike artificial selection, the effects (the structure and articulation with the environment that the organisms exhibit) are achieved without intentional design. In this regard, natural selection exemplifies the natural science tradition of reading mind out of nature. But natural selection gives this tradition a startling twist. It reads mind out of one realm of nature in which design, adaptation, and purpose are quite salient. When Darwin's theory suggested design without a designer, the notion seemed to many to be self-contradictory. This is the locus of the central problem raised by Skinner's account of radical behaviorism. It raises the specter of intelligence without mind.

These issues are nicely focused in some remarks by Elliott Sober. Sober notes a connection between Darwin's analogy and Skinner's. Sober examines structural and methodological similarities among evolutionary biology, behavioral psychology, and game-theoretic approaches to rational choice. Sober (1985) remarks that

> rational deliberation and natural selection are structurally *analogous*. . . . The generality of game theory as a descriptive (as well as normative) methodology derives from the fact that optimizing mechanisms can take a variety of forms—human decision making and evolution by natural selection being our two cases in point. (pp. 196–197)

According to Sober, these similarities indicate that "the time has perhaps come for us to think

not of behaviorism versus mentalism but of behaviorism *and* mentalism" (p. 197). Sober's discussion raises a basic issue concerning relations among mentalism, behaviorism, and selectionist theories.

In Sober's view, Darwin's analogy highlights the fact that both natural selection and rational choice are optimizing mechanisms subject to description by the same mathematical structures. These structural similarities have, in fact, not only shown promise as a basis for mathematical treatments of the processes of rational choice (von Neumann & Morgenstern, 1944) and natural selection (Maynard Smith, 1984), but they have also been exploited in treatments of operant conditioning as well (Houston & McNamara, 1988; Staddon, 1980, 1983). This literature lends support to Darwin's view that selection processes are insightfully compared with the decisions and actions of a rational agent selecting according to some standard. Nevertheless, Skinner rejected the suggestion that behaviorism and mentalism are complementary, and he (1984, compare Staddon & Hinson, 1983; Williams, 1990, 1991) expressed his skepticism about the scientific promise of optimality models of behavioral adaptation. Darden and Cain (1989) located the problem raised by this difference of opinion for the characterization of selection type theories. They noted that although it seems natural to describe selection processes in terms of "an agent selecting according to a criterion . . ., 'agent' brings inappropriate negative analogy from the artificial to the natural case" (p. 112). It seems clear that one central and so far unresolved problem in the characterization of selection type theories (and, hence, in the characterization of selection processes like reinforcement) is to determine whether there is a significant disanalogy between natural and artificial selection. Skinner's critique of mentalism suggests that a negative analogy exists in features shared by animistic, vitalistic, and mentalistic theories. The problem is to specify which features these are and to indicate why they are conceptually and methodologically significant.

MENTALISTIC AND TELEOLOGICAL PROCESSES

Historical and conceptual considerations suggest that one methodologically significant similarity between mentalistic and vitalistic theories is that they describe processes that are teleological in the sense required by Aristotle's doctrine of final causation. The significance of this proposal emerges most clearly from consideration of differences among three distinct types of explanatory theory that can be called teleological, mechanistic, and selectionist. Each type of theory is distinguished by a distinctive form of explanatory principle (or ideal of natural order). Each is exemplified by well-known examples of explanatory theories. The basic differences can be sketched rather succinctly.

Teleological Theories

Teleological theories are what define or describe goal-directed (or directively organized) systems and processes. Standard examples of such systems and processes are homing torpedoes, heat seeking or map-guided missiles, temperature regulation processes in homes and in mammals, the food-seeking activity of predators, the avoidance behavior of prey, and so on. What marks a system or process as goal directed is that it does what, under prevailing (and often changing) circumstances, is instrumental for attaining its goals. A predator seeking food will do (within limits) what will make getting food more likely. Furthermore, as circumstances change what is required, the predator will do (within limits) what the new circumstances require. When a fox chases a rabbit, the behavior of the fox changes (e.g., it changes direction, it runs, it jumps, it digs) as changes in the behavior of the rabbit and changes in the terrain change what is appropriate under the circumstances for catching the rabbit. A general way of describing goal direction of this sort is suggested by Bennett (1990; cf. Braithwaite, 1953; Nagel, 1977; Taylor, 1964). What a goal-directed system does is a function of its *instrumental properties* (Bennett, 1990, p. 38). An instrumental property is just a "means–end" relationship determined by the causal structure of the environment. Some examples are Gibsonian affordances, contingencies in an experimental conditioning chamber, and act–consequence relations in a standard decision matrix. In general, a system s has instrumental property B/G when and only when prevailing circumstances are such that the occurrence of B increases the probability of the occurrence of G. It should be clear that a system can have instrumental properties even though none of

its behavior is determined by them. A fox can have the instrumental property "turning 90 degrees right/catching a rabbit" even when it is not engaged in pursuing prey (e.g., because it is sleeping or otherwise engaged).

To say changes in a system, s, are a function of changes in its instrumental properties is simply to say that s conforms to a principle of the following form:

$$(b)\ (t)\ ([b/G]st \rightarrow bst + d).$$

Here b is a variable that takes as values descriptions of changes in the system in question. This principle says, roughly, that s (e.g., the fox) will do whatever is appropriate under prevailing circumstances (at time t) for later bringing about G (e.g., catching the rabbit at time $t + d$). This is a rough formulation, and some of the details matter, but I hope the formulation can serve to make three theses intuitively clear.

The first thesis is that goal-directed systems are systems that conform to principles of the form just exhibited (call them teleological principles). The second thesis is that teleological explanations are explanations that appeal to teleological principles. The third thesis is that appeals to final causation are simply appeals to teleological explanations of the sort just described. These theses provide an interpretation of Bacon's view that appeals to final causes are inappropriate in modern natural science. Thus, teleological explanations are inappropriate. There will be occasion to return to this view later. At this point it is sufficient to have sketched the view itself. Some of its significance emerges in contrast with mechanistic and selectionist theories.

Mechanistic Theories

Mechanistic theories seem to be paradigmatic for traditional conceptions of explanation in modern natural science (e.g., Hempel, 1965; Salmon, 1984). Mechanistic theories are what describe and define mechanistic processes. Some of the paradigm cases of mechanistic processes are deterministic. The changes in momentum that result when billiard balls collide provide a clear example of such deterministic relations. Some mechanistic processes are probabilistic and not deterministic. The change in probability of developing lung cancer produced by cigarette smoking may be an example of nondeterministic processes that are mechanistic. The prime exemplars of mechanistic theories and principles are those that constitute classical (including statistical) mechanics. Newton's laws (of motion and universal gravitation) constitute what is, perhaps, the best known example of a mechanistic (and in this case, deterministic) theory. The laws of motion (like principles that define and describe other mechanistic systems) take the following form:

$$(x)\ (t)\ [Cxt \rightarrow Ext + d].$$

Mechanistic explanations are explanations that appeal only to such principles. Two features of such principles are crucial for the purposes at hand: The later state of affairs is a (deterministic or probabilistic) function of an earlier (and, ideally, spatially and temporally proximate) state of affairs. Neither the earlier state of affairs nor the later state of affairs is an instrumental property of the system. This second feature of mechanistic principles entails that they are not teleological. Mechanistic principles do not provide teleological explanations.

The thesis that modern natural science rejects final causation and is engaged in the search for efficient causal explanations is often understood to mean that modern natural science is engaged in the search for mechanistic theories. The contrast between mechanism and teleology is not, however, sufficient for interpreting Skinner's thesis that scientific psychology is the search for causal and not mentalistic explanations: Skinner's thesis identifies an influential type of scientific explanation that is causal but that is neither mechanistic nor teleological. This is the type of explanation provided by selectionist theories.

Selectionist Theories

The primary example of a selectionist theory is, of course, the Darwinian theory of evolution by natural selection, according to which nature acts on naturally occurring variation between individual organisms in ways that affect the probability of reproductive success. These selection processes involve three main steps that occur in the following temporal order: First, an array of variants is generated (e.g., white moths and peppered moths in some proportion). Second, there are interactions of variants with environments that have different effects on the existing variants (e.g., on soot-

blemished surfaces, peppered moths are better camouflaged than white moths and, so, are less often consumed by predators). Third, a pool of variants now exists that differs from the original as a result of the interaction (e.g., the proportion of peppered moths is higher than before the interaction).

Two different sorts of principles specify relations between the stages of the cycle: (a) Principles of generation specify the processes by which an array of variants is generated from a previous array, and (b) principles of selection specify both the agents of selection and the criteria of selection involved in interactions between members of an existing pool of variants and the environments in which they exist.

In the case of natural selection the *agents* of selection are whatever features of the environment differentially affect probability of reproductive success. The *criterion* of selection is enhancement of the probability of reproduction in the environment faced by the variants. In contemporary evolutionary biology, the accepted principles of generation are those of classical and molecular genetics. There is, of course, some debate (e.g., Lenski & Mittler, 1993) about whether directed variation occurs. It seems clear, however, that the principles of generation are presumed to be nonteleological and are more likely mechanistic.

The distinctive principle here, namely the principle of (natural) selection, is neither mechanistic nor teleological. It differs from teleological principles in that teleological principles make change a function of instrumental properties, that is, of actual or anticipated future consequences. Selection principles, in contrast, make change a function of past consequences. Specifically, selection principles do not predict the development of those characteristics a changed environment requires for the reproductive success of organisms in that environment. Teleological principles entail such predictions (for discussion, see Ringen, 1985, 1993b). In addition, even though the generation of variation, the process of selection, and the interaction of variation and selection are all currently understood to be efficient causal processes, it is quite clear that selection processes are not mechanistic. Mechanistic systems are governed solely by principles that make later states a function of temporally proximate antecedent states. Selection principles make current states a function of specific past consequences of still earlier states. Hence, current states are not just a function of their temporally proximate antecedents. Indeed, selection principles make current states a function of the kind of three-term contingency familiar to behaviorists as defining operant behavior (for discussion, see Ringen, 1976).

What makes Darwinian selection processes distinctive is that they are neither mechanistic nor teleological, yet like mechanistic processes they are causal processes, and like teleological processes they can produce adaptation—a "fit" between the characteristics of an organism and the characteristics the current environment requires for reproductive success.

Details of these similarities and differences need to be carefully worked out, but for the purposes at hand it is most important to sketch the intuitive differences among teleological, mechanistic, and selectionist explanatory theories. These distinctions provide an interpretation of Skinner's thesis that operant behaviorism treats purpose and intention in intelligent action in the same way that Darwin treats intentional design in the realm of biological adaptation. The leading idea is that natural science is the search for efficient causal explanations of behavior and the rejection of final causation. Prior to clear appreciation of the significance of natural selection, this might reasonably have been taken to imply that scientific psychology must be the search for mechanistic explanations. Appreciation of the significance of natural selection permits a broader conception of scientific psychology: Scientific psychology is the search for mechanistic and selectionist theories and the rejection of teleological theories.

This interpretation of Skinner's views provides a promising perspective on the history and prospects of scientific psychology. It corrects existing accounts of relations among various forms of behaviorism. It also clarifies relations between behaviorism and both classical and contemporary cognitivism. It is useful to begin with discussion of behaviorism.

NEOBEHAVIORISM: SOME CONTRASTS

The works of Tolman, Hull, and Skinner differ in ways that illustrate the contrasts be-

tween teleological, mechanistic, and selectionist explanatory theories. These three writers all agree that organisms are, in the ordinary sense, goal-directed systems: On casual inspection, the behavior of organisms conforms to teleological principles. Beyond that, deep disagreements are evident. One of these disagreements concerns the type of explanation that goal-directed behavior requires. The issues raised are simply glossed over by influential views of what distinguishes behaviorism and cognitivism (for discussion see Amundson, 1983; Ringen, 1976, 1993a; L. Smith, 1986). The issues are highlighted (and clarified) by the proposed interpretation of Skinner's defense of radical behaviorism.

E. C. Tolman

Tolman (1948) asserted:

> We believe that in the course of learning, something like a field map of the environment gets established. . . . And, it is this tentative map, indicating routes and paths and environmental relationships, which *finally determines* what responses the animal will finally release. . . . maps may be correct or incorrect in the sense that they may (or may not), *when acted upon,* lead successfully to the animal's goal. (pp. 244–245, emphasis added)

According to Tolman, organisms are not only goal-directed systems; their goals and cognitive maps both determine and explain what the organism does. This identifies Tolman as engaged in the search for *mentalistic* theories. There is reason to conclude that mentalistic theories are teleological; this highlights the historical and methodological significance of Tolman's contrast between his purposive behaviorism and more traditional behavioristic formulations of learning in terms of either underlying physiological processes or processes of conditioning. The main point is that mentalistic theories are teleological because they treat behavior as a function of specific instrumental properties. That this is so is often not acknowledged. It is important to consider why it is so.

What rats and people do often conforms to teleological generalizations. When environments change so that what is appropriate for realizing some future state also changes, then what the organism does often changes accordingly. This pattern suggests both intelligence and mind, but the pattern that indicates intelligence can be conceptually severed from explanation in terms of states of the mind: Behavior can be goal directed without being a manifestation of mind. The activities of thermostats, heat-seeking missiles, and paramecia are examples that suggest this possibility. What is crucial to the concept of mind in commonsense "folk psychology" and in classical cognitivism is the presence of mental representations (e.g., the objects of belief and desire) that guide and explain behavior. Tolman's cognitive maps constitute mental representations in just this sense. Tolman's claim that cognitive maps determine and explain what organisms do marks him as a mentalist in every sense that classical cognitivists are (for discussion see Amundson, 1983). It is important to see why such mentalistic explanations are teleological.

The main point is this: Mentalistic explanations make behavior a function of internal (mental) representations of instrumental properties and not directly a function of instrumental properties that exist independently of whether the organism registers or represents them or not. Cognitive maps are internal representations of instrumental properties. A rat guided by a cognitive map does what is appropriate in the environment represented by its map. If the rat's actual environment is sufficiently similar to that represented by its cognitive map, then what the rat does matches what the actual environment requires. In cases in which the actual environment and the internally represented (i.e., intentional) environment are sufficiently different, the rat makes a mistake: What it does is inappropriate for attaining its goals (in the actual environment), but what it does is goal directed, in that it is appropriate for environments like that represented by its cognitive map. Behavior still conforms to a (mentalistic) teleological principle: The behavior is a function of instrumental properties in the environment represented by a cognitive map. Teleological principles need not be mentalistic, but mentalistic explanations are teleological. This point has been defended in the philosophical literature (see especially Bennett, 1990; Taylor, 1964) and is important because it challenges the widespread assumption that mentalistic explanations are simply efficient causal expla-

nations (see especially Braithwaite, 1953; Davidson, 1963; Fodor, 1987; Fodor, Bever, & Garrett, 1974; Nagel, 1977).[1] This is an assumption that Skinner (e.g., 1977) also rejects.

Clark Hull

The influential views of Clark Hull present a contrast to those of Tolman. Hull (1943) asserted:

> The present approach does not deny the molar reality of purposive acts (as opposed to movement) of intelligence, of insight, of goals, of intents, of striving, or of value; (on the contrary) we hope ultimately to show the logical right to the use of such concepts by deducing them as secondary principles from more objective primary principles. (p. 25)

He also mentioned that "Many of the more promising of these principles were roughly isolated by the Russian physiologist, Pavlov, and his pupils by means of conditioned-reflex experiments on dogs" (p. 20).

According to Hull, the behavior of organisms may conform to teleological principles, but scientific explanations of behavior must not appeal to goals or intentions. They must appeal to "more objective" primary principles. Hull identifies such principles by reference to the work of Galileo, Newton, and Pavlov. In his early work, Hull (Amsel & Rashotte, 1984) treated Pavlovian conditioning as a "mechanistic process of association" that worked by simple contiguity.[2] This identifies Hull as engaged in the search for mechanistic theories and highlights the historical and methodological significance of his opposition to mentalistic and teleological explanations in scientific psychology.

B. F. Skinner

In contrast to Tolman and Hull, Skinner (1986) asserted that "operant behavior is the field of intention purpose and expectation. It deals with that field precisely as the theory of evolution has dealt with another kind of purpose" (p. 716). In this account, natural selection and operant conditioning are similar. He (Skinner, 1981) termed them both instances of selection by consequences. Natural selection is the original model, of which operant conditioning is a second instance. Skinner explicitly contrasted this model of explanation with both mentalistic and mechanistic (stimulus–response) models. This theme appears frequently in Skinner's work, but most explicitly in Skinner (1981).

In the interpretation proposed here, these remarks identify Skinner as engaged in the search for selectionist explanations. This interpretation highlights the historical and methodological significance of Skinner's distinction between operant and respondent conditioning and his attacks on mentalism. These are, of course, the components of Skinner's version of radical behaviorism. Radical behaviorism must be understood in relation to Skinner's insistence that scientific psychology is the search for the causes of behavior, and mentalistic explanations do not contribute to that search. The reasons for this insistence emerge from comparing natural selection and operant conditioning with each other and with vitalism and mentalism, respectively.

The proposed interpretation of radical behaviorism clarifies relations between the three major neobehaviorists and the view of natural science as the search for efficient causes and the rejection of teleology. Roughly, in embracing mentalism, Tolman embraced teleology. Early on, Hull and Skinner, in their different ways, each rejected teleology. Hull

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[1] This raises a set of philosophical issues that deserve mention even though, in this essay, detailed discussion is impossible. It is often argued (Braithwaite, 1953; Nagel, 1977) that teleology is problematic only in those cases in which the ascription of mental states seems to be unwarranted. In that case, it is argued, no antecedent state is an obvious candidate for bringing about the goal-directed behavior. For this reason, in this case, explanatory vacuity, a breech in the causal chain, or backward causation all seem to threaten. In the contrasting case, in which ascriptions of propositional attitudes seem natural, the mental state can serve as the antecedent cause. The analysis proposed here challenges the presumption of this argument. Instrumental properties are antecedents of the activities they explain, whether they are the object of mental representation or not. Furthermore, the character of instrumental properties helps solve a nagging problem about mental states, namely what distinguishes them (conceptually) from other internal (but nonmental) states that cause behavior.

[2] In his later work, Hull (e.g., 1943) seems to be moving toward a selectionist theory. In this work, the contrast between Skinner and Hull lies in Hull's view that classical (Pavlovian) conditioning is a special case of "selective learning" that involves reinforcement of contiguous internal events in accord with principles of instrumental (operant) conditioning (for discussion, see Sayre, 1976, and Spence, 1956).

embraced mechanism (and S–R associationism). Skinner embraced selectionism. Each proposes a different model of how the goal-directed behavior of organisms is to be explained. Consider the pursuit behavior of a fox. Tolman's view suggests that it is guided by the fox's beliefs and desires. Hull's early view suggests that it is the exercise of sets of stimulus–response associations previously established by a process like Pavlovian (respondent) conditioning. Skinner's model suggests that it is behavior controlled by discriminative stimuli that are established by a past history of operant conditioning. These distinctions provide a basis for a postpositivist account of the conceptual and methodological issues that divide behaviorists from classical cognitivists and for exploring conceptual and historical relations between behaviorism and contemporary cognitive science.

COGNITIVISM AND BEHAVIORISM

Assessments of the relative merits of behaviorism and cognitivism often begin with two arguments: First, behaviorism is the application to scientific psychology of logical positivist philosophy of science. Second, conditioning principles are associationist mechanisms. Each argument is taken to support the scientific superiority of cognitivism in relation to behaviorism.

The first argument (Block, 1980; Fodor, 1968; Sober, 1992; Taylor, 1964) is an argument against logical behaviorism. According to this argument, behaviorism requires that theoretical terms in scientific psychology must be operationally defined. So construed, behaviorism is burdened with two logical positivist doctrines that are widely held to be completely discredited: (a) Theoretical terms and observation terms in science can be sharply distinguished, and the truth or falsity of observation statements can be determined directly and without assuming the truth of any theoretical statements under test; and (b) any theoretical terms that are scientifically legitimate must be logically linked with observation terms. Critics of logical behaviorism maintain that the main difference between cognitivism and behaviorism is that cognitivists endorse theories whose (mentalistic) terms cannot satisfy these logical positivist constraints. Behaviorist skepticism about mentalism is traced to this fact. Cognitivism is said to be preferable to behaviorism because good scientific psychology seems to require such theories, and behaviorism prohibits them for no good reason: The logical positivist doctrines alleged to justify the behaviorist restrictions have long since been discredited on independent philosophical grounds. In particular, it has been shown that the first constraint cannot be clearly formulated (Quine, 1953) and that both constraints are violated by virtually every clear example of legitimate scientific theory, ranging from atomic theory to the theory of evolution by natural selection (Hanson, 1958; Kuhn, 1962).

The second argument is a criticism of stimulus–response associationism. According to this argument, organisms exhibit behavioral capacities that are inexplicable by processes that depend solely on the existence or formation of proximate cause–effect (e.g., S–R) relations. Mentalistic processes embody no such restrictions and, so (it is argued), cognitivism is preferable to behaviorism (Fodor, Bever, & Garrett, 1968, 1974).

Recent work (L. Smith, 1986) has shown that the argument against logical behaviorism misrepresents the differences between cognitivism and the behaviorisms of Tolman, Hull, and Skinner. Specifically, the commitment of each of these behaviorists to an empirically based epistemology is inconsistent with commitment to the logical positivist doctrines with which cognitivist assessments of behaviorism begin. Logical positivists hold that methodological principles (such as verificationist—e.g., operationist—criteria of empirical scientific significance) can be established a priori. In contrast, behaviorists (e.g., Skinner, 1957) maintain that methodological principles must be evaluated just like other explanatory principles in empirical science, by painstaking observation and experiment and, in the case at hand, by attending to the behavior of scientists. Furthermore, any criticism of S–R associationism aimed at behaviorists such as Skinner and Tolman is wide of the mark. We need a new characterization of the distinctions between classical cognitivism and behaviorism that explains behaviorist skepticism about mentalism. Under the interpretation proposed here, Skinner's defense of radical behaviorism provides this new characterization. This characterization suggests a different assessment of the relative merits of behaviorism and cogni-

tivism than that based on the characterization of behaviorism as applied logical positivism.

Furthermore, Tolman's purposive behaviorism, classical cognitivism, and common-sense belief–desire psychology all endorse mentalistic explanatory theories, and it is the character of such theories that marks the fundamental methodological difference between classical cognitivism and behaviorism. Cognitivists endorse mentalistic explanations and behaviorists reject them. This difference is of considerable methodological significance.

Both Hull and Skinner considered science to be the search for efficient causal explanations, and both Hull and Skinner opposed animistic and vitalistic explanations in science. They treated mentalistic explanations as explanations in the animistic and vitalistic mode. The problem is to identify what it is about the search for efficient causes of behavior that stands in significant opposition to animism, vitalism, and mentalism. Mind/matter dualism won't do to set up any useful contrast with contemporary cognitivism (including Tolman's purposive behaviorism). Most of the contemporary cognitivist critics of behaviorism are themselves physicalists or materialists of one sort or another. We must look elsewhere.

According to the account presented here, mentalistic explanation is a form of teleological explanation, and teleological and efficient causal explanations are significantly different. It has been argued here that this is the core of the historically, conceptually, and methodologically significant distinctions between behaviorism and classical cognitivism.

Differences between the explanations recommended by Hull and Skinner are simply differences between mechanistic (e.g., associationist) and selectionist explanations. The similarity between the two is that neither mechanistic explanation nor explanation in terms of selection by consequences is teleological in the sense that mentalistic explanations are. Teleological explanations postulate a distinctive kind of directed variation. In particular, the teleological principles that define goal-directed systems require that goal-directed systems be disposed to exhibit behavior that under prevailing circumstances is appropriate for attaining some specified end. Mechanistic and selectionist explanations do not postulate this kind of directed variation (see Porpora, 1980; Ringen, 1976, 1985, 1993a, 1993b). Furthermore, there is historical basis for concluding that various forms of vitalism (e.g., that embodied in the teleomechanistic program in biology inspired by Kant, 1968, and endorsed by the 19th century embryologist Karl Ernst von Baer and his followers) embrace a form of teleology that fits both this analysis and a proper reconstruction of the notion of final causation presented by Aristotle. (In this regard compare the analysis Lenoir, 1982, attributes to Kant and von Baer, the analysis presented by Taylor, 1964, and Bennett, 1990, Aristotle's remarks in *De Anima,* 1907, and Hans Driesch's 1914 account of the history of vitalism.) This form of teleology does not fit any of the positivist caricatures of vitalism. Hence, the kind of mentalism common to folk psychology, Tolman's purposive behaviorism, and classical cognitivism embodies principles that are teleological without postulating psychic forces, backward causation, or vacuous principles whose antecedents and consequents cannot be independently described or identified. The main idea is that the behavior of "intentional systems" changes in ways that are best explained as behavior that is appropriate for goal attainment in a environment like that the system believes (i.e., mentally represents) itself to be in. If this hypothesis is correct, then behaviorist concerns about cognitivism can be treated as a case of scientific concerns about final causation. At present, the similarities are sufficient to serve as the basis for a behaviorist challenge: Cognitivists need to show how the mental representations they invoke can be explicated and can serve their intended role without invoking teleological principles and still constitute a basis for distinguishing cognitivism and behaviorism. Efforts to articulate selectionist (Dennett, 1987; Papineau, 1987) and mechanistic (Fodor, 1987) accounts of traditional notions of intentionality and representation have not been successful. Hence, until this challenge is met, it seems reasonable to hold that mentalism embodies teleology of exactly the sort Skinner and Hull opposed, and that this contrast between defenders and opponents of teleology provides a promising basis for reconstructing the contrasts required for a conceptualist assessment of the relative merits of behaviorism and cognitivism. This reconstruction has significant implications.

Skinner's opposition to cognitivism derives from the conclusion that it involves a kind of teleology that has been embodied in research

programs (such as vitalism in biology) that in the history of science have been substantive dead ends. Thus, the Skinner/Hull view of the opposition between scientific psychology and mentalism is an instance of an influential view of the history of science: The modern natural scientific tradition arose from a break from the Aristotelian doctrine of final causation and a shift in emphasis to the search for efficient causes. Progress in this tradition is marked by the progressive efforts to read mind out of nature. For better or worse, for both Hull and Skinner (as well as for contemporary eliminative materialists), naturalistic psychology and epistemology represent the natural extension and capstone of this process. Classical cognitivists (Fodor et al., 1974; Johnson-Laird, 1983; Pylyshyn, 1984), in contrast, endorse "an experimental mentalism," but in the noncognitivist view this is inconsistent with a basic lesson drawn from the natural-science tradition: The search for teleological principles is no longer viable. From this perspective, mentalism and the type of cognitivism modeled on it represent a form of Aristotelian psychology, and the contemporary cognitivist "revolution" appears to be a reactionary rejection of behaviorism comparable to the "romantic" reaction to Newtonianism in the 19th century or to the vitalistic movement that temporarily eclipsed Darwinism in the early decades of the 20th century (Catania, 1987).

These arguments are not conclusive, but they are worth careful articulation and scrutiny. They promise a historically accurate postpositivist account of differences between influential forms of behaviorism and between behaviorism and those forms of cognitivism that endorse mentalism. In addition, they provide a point from which to begin considering whether contemporary cognitive (e.g., neurocomputational; Churchland & Sejnowski, 1992) science is more closely related (conceptually and historically) to behaviorism or to classical (mentalistic) cognitivism. For example, it provides a basis for examining the methodological and conceptual significance of selectionist (Edelman, 1992; Lubinski & Thompson, 1987), connectionist (Rescorla, 1988; Rumelhart & McClelland, 1986; Sutton & Barto, 1981), and representationalist (Gallistel, 1990) models of learning, development, and performance.

There is considerable room for debate on these issues. Two references can serve to fix the opposite ends of the spectrum of views in current discussion. Skinner (1990) argued that "Cognitive science is the creation science of psychology as it struggles to maintain the position of a mind or self" (p. 1209). Most classical and contemporary cognitivists would be uncomfortable with this comparison, and there are nonmentalistic approaches to the investigation of cognitive capacities that the comparison may not fit (e.g., Churchland & Sejnowski, 1992; Edelman, 1992). But, there are also explicit arguments in the philosophical literature (Plantinga, 1993) that the classical (mentalistic) cognitivist notion of mental function (and the parallel notion of biological function) is unintelligible apart from the hypothesis that the minds (and organisms) are intentional productions of a divinely intelligent artificer. It is worth noting that this link is not entailed by the conception of teleology presented in this essay. Goal-directed systems and the functions of the systems that contribute to goal-directed activities are intelligible apart from the hypothesis of intentional design. Even so, Skinner's arguments suggest that mentalism is problematic from a natural-science perspective.

CONCLUSION

Burtt (1951) argued that central problems of modern philosophy arise from the progressive elimination of mental categories from scientific accounts of natural phenomena. The preceding discussion of the analogies of Darwin and Skinner suggests that central problems of modern scientific psychology and biology and of the philosophy of these disciplines have a similar historical (and conceptual) origin. Specifically, they have their origin in that aspect of the modern scientific tradition which emphasizes the rejection of the Aristotelian doctrine of final causation and sets the goal of discovering laws of efficient causal succession. Skinner's arguments suggest that the debates between cognitivists and behaviorists are largely debates about the importance of teleology in scientific psychology and biology. In this view, defenses of classical cognitivism pose an important dilemma: Either we must be skeptical of the view of modern natural science as representing a break with the Aristotelian doctrine of final causation, or we must be prepared to view the conceptual and methodological foundations of psychology and biology as

being distinctly different from the natural sciences that do exemplify this view. In contrast, defenses of radical behaviorism offer a means of escaping both horns of the dilemma, and thus offer a program for pursuing biology and psychology within the natural-science tradition, defined by the modern break from final causation.

REFERENCES

Amsel, A., & Rashotte, M. (1984). *Mechanisms of adaptive behavior, with commentary.* New York: Columbia University Press.

Amundson, R. (1983). E. C. Tolman and the intervening variable: A study in the epistemological history of psychology. *Philosophy of Science,* **50,** 268–282.

Aristotle. (1907). *De anima* (R. D. Hicks, Trans.). Cambridge: Cambridge University Press.

Bacon, F. (1905). *Novum organum.* In J. Robertson (Ed.), *Philosophical works of Francis Bacon.* London: Longman & Co.

Bennett, J. (1990). *Linguistic behaviour.* Indianapolis: Hackett.

Block, N. (Ed.). (1980). *Readings in philosophy of psychology.* Cambridge, MA: Harvard University Press.

Braithwaite, R. (1953). *Scientific explanation; a study of the function of theory, probability, and law in science.* Cambridge: Cambridge University Press.

Burtt, E. (1951). *The metaphysical foundations of modern science* (rev. ed.). New York: The Humanities Press.

Catania, A. C. (1987). Some Darwinian lessons for behavior analysis: A review of Bowler's *The Eclipse of Darwinism. Journal of the Experimental Analysis of Behavior,* **47,** 249–257.

Churchland, P. S., & Sejnowski, T. (1992). *The computational brain.* Cambridge, MA: The MIT Press.

Coleman, S. R. (1981). Historical context and systematic functions of the concept of the operant. *Behaviorism,* **9,** 207–226.

Coleman, S. R. (1984). Background and change in B. F. Skinner's metatheory from 1930 to 1938. *Journal of Mind and Behavior,* **5,** 471–500.

Darden, L. (1983). Reasoning by analogy in scientific theory construction. In R. Michalski (Ed.), *Proceedings of the international machine learning workshop* (pp. 32–40). Urbana-Champaign, IL: University of Illinois.

Darden, L., & Cain, J. A. (1989). Selection type theories. *Philosophy of Science,* **56,** 106–129.

Darwin, C. (1909). *The foundations of The Origin of Species: Two essays written in 1842 and 1844* (Francis Darwin, Ed.). Cambridge: Cambridge University Press.

Darwin, C. (1923). *The origin of species by means of natural selection* (6th ed.). New York: Appleton.

Davidson, D. (1963). Actions, reasons, and causes. *Journal of Philosophy,* **60,** 685–700.

Dennett, D. (1987). *The intentional stance.* Cambridge, MA: MIT Press.

Driesch, H. (1914). *The history and theory of vitalism* (C. K. Ogden, Trans.). London: Macmillan.

Edelman, G. M. (1992). *Bright air, brilliant fire: On the matter of the mind.* New York: Basic Books.

Fodor, J. A. (1968). *Psychological explanation; an introduction to the philosophy of psychology.* New York: Random House.

Fodor, J. A. (1987). *Psychosemantics: The problem of meaning in the philosophy of mind.* Cambridge, MA: MIT Press.

Fodor, J. A., Bever, T., & Garrett, M. (1968). A formal limitation on associationism. In T. Dixon & D. Horton (Eds.), *Verbal behavior and general behavior theory* (pp. 582–585). Englewood Cliffs, NJ: Prentice-Hall.

Fodor, J. A., Bever, T. G., & Garrett, M. F. (1974). *The psychology of language: An introduction to psycholinguistics and generative grammar.* New York: McGraw Hill.

Gallistel, C. R. (1990). *The organization of learning.* Cambridge, MA: MIT Press.

Ghiselin, M. (1969). *The triumph of the Darwinian method.* Berkeley: University of California Press.

Hanson, N. R. (1958). *Patterns of discovery: An inquiry into the conceptual foundations of science.* Cambridge: Cambridge University Press.

Hempel, C. (1965). *Aspects of scientific explanation, and other essays in the philosophy of science.* New York: Free Press.

Houston, A. I., & McNamara, J. M. (1988). A framework for the functional analysis of behaviour. *Behavioral and Brain Sciences,* **11,** 117–163.

Hull, C. (1930). Knowledge and purpose as habit mechanisms. *Psychological Review,* **37,** 511–525.

Hull, C. L. (1943). *Principles of behavior: An introduction to behavior theory.* New York: Appleton-Century.

Hull, D. (1988). *Science as a process: An evolutionary account of the social and conceptual development of science.* Chicago: University of Chicago Press.

Johnson-Laird, P. (1983). *Mental models: Towards a cognitive science of language, inference, and consciousness.* Cambridge, MA: Harvard University Press.

Kant, I. (1968). *Critique of judgment* (J. H. Bernard, Trans.). New York: Hafner Publishing Co.

Kuhn, T. (1962). *The structure of scientific revolutions.* Chicago: University of Chicago Press.

Lakatos, I. (1978). *The methodology of scientific research programmes: Philosophical papers.* London: Cambridge University Press.

Laudan, L. (1977). *Progress and its problems: Toward a theory of scientific growth.* Berkeley: University of California Press.

Lenoir, T. (1982). *The strategy of life: Teleology and mechanics in 19th century German biology.* Boston: Reidel.

Lenski, R. E., & Mittler, J. E. (1993). The directed mutation controversy and neo-Darwinism. *Science,* **259,** 188–194.

Lubinski, D., & Thompson, T. (1987). An animal model of the interpersonal communication of interoceptive (private) states. *Journal of the Experimental Analysis of Behavior,* **48,** 1–15.

Mahoney, M. J. (1989). Scientific psychology and radical behaviorism: Important distinctions based in scientism and objectivism. *American Psychologist,* **44,** 1372–1377.

Maynard Smith, J. M. (1984). Game theory and the evolution of behaviour. *Behavioral and Brain Sciences,* **7,** 95–125.

Mayr, E. (1961). Cause and effect in biology. *Science,* **134,** 1501–1506.

Mayr, E. (1976). *Evolution and the diversity of life.* Cambridge, MA: Harvard University Press.

Nagel, E. (1977). Teleology revisited: The Dewey lectures 1977. *Journal of Philosophy,* **74,** 261–301.

Papineau, D. (1987). *Reality and representation.* New York: Basil Blackwell.

Pavlov, I. P. (1927). *Conditioned reflexes: An investigation of the physiological activity of the cerebral cortex.* (G. V. Anrep, Trans.). London: Oxford University Press.

Plantinga, A. (1993). *Warrant and proper function.* New York: Oxford University Press.

Porpora, D. V. (1980). Operant conditioning and teleology. *Philosophy of Science,* **47,** 568–582.

Pylyshyn, Z. W. (1984). *Computation and cognition: Toward a foundation for cognitive science.* Cambridge, MA: MIT Press.

Quine, W. V. (1953). Two dogmas of empiricism. In *From a logical point of view: 9 Logico-philosophical essays* (2nd ed., pp. 20–47). New York: Harper and Row.

Rescorla, R. W. (1988). Pavlovian conditioning: It's not what you think. *American Psychologist,* **43,** 151–160.

Ringen, J. D. (1976). Explanation, teleology, and operant behaviorism: A study of the experimental analysis of purposive behavior. *Philosophy of Science,* **43,** 223–253.

Ringen, J. (1985). Operant conditioning and a paradox of teleology. *Philosophy of Science,* **52,** 565–577.

Ringen, J. D. (1986). The completeness of behavior theory: A review of *Behaviorism, science, and human nature,* by Barry Schwartz and Hugh Lacey. *Behaviorism,* **14,** 29–39.

Ringen, J. D. (1993a). Critical naturalism and the philosophy of psychology. *New Ideas in Psychology,* **11,** 153–177.

Ringen, J. (1993b). Dennett's intentions and Darwin's legacy. *Behavioral and Brain Sciences,* **16,** 386–389.

Rumelhart, D. E., & McClelland, J. L. (Eds.). (1986). *Parallel distributed processing: Explorations in the microstructure of cognition* (Vols. 1–2). Cambridge, MA: MIT Press.

Salmon, W. C. (1984). *Scientific explanation and the causal structure of the world.* Princeton, NJ: Princeton University Press.

Sayre, K. M. (1976). *Cybernetics and the philosophy of mind.* Atlantic Highlands, NJ: Humanities Press.

Skinner, B. F. (1937). Two types of conditioned reflex: A reply to Konorski and Miller. *Journal of General Psychology,* **16,** 272–279.

Skinner, B. F. (1957). *Verbal behavior.* New York: Appleton-Century-Crofts.

Skinner, B. F. (1969). *Contingencies of reinforcement: A theoretical analysis.* New York: Appleton-Century-Crofts.

Skinner, B. F. (1977). Why I am not a cognitive psychologist. *Behaviorism,* **5,** 1–10.

Skinner, B. F. (1981). Selection by consequences. *Science,* **213,** 501–504.

Skinner, B. F. (1984). The evolution of behavior. *Journal of the Experimental Analysis of Behavior,* **41,** 217–221.

Skinner, B. F. (1986). Is it behaviorism? *Behavioral and Brain Sciences,* **9,** 716.

Skinner, B. F. (1990). Can psychology be a science of mind? *American Psychologist,* **45,** 1206–1210.

Smith, L. D. (1986). *Behaviorism and logical positivism: A reassessment of the alliance.* Stanford, CA: Stanford University Press.

Smith, T. L. (1983). Skinner's environmentalism: The analogy with natural selection. *Behaviorism,* **11,** 133–154.

Sober, E. (1983). Mentalism and behaviorism in comparative psychology. In D. W. Rajecki (Ed.), *Comparing behavior: Studying man studying animals* (pp. 113–142). Hillsdale, NJ: Erlbaum.

Sober, E. (1985). Methodological behaviorism, evolution, and game theory. In J. H. Fetzer (Ed.), *Sociobiology and epistemology* (pp. 181–200). Boston: Reidel.

Sober, E. (1992). *Core questions in philosophy.* New York: Macmillan.

Sohn, D. (1976). Two concepts of adaptation: Darwin's and psychology's. *Journal of the History of the Behavioral Sciences,* **12,** 367–375.

Spence, K. W. (1956). *Behavior theory and conditioning.* New Haven, CT: Yale University Press.

Staddon, J. E. R. (1979). Operant behavior as adaptation to constraint. *Journal of Experimental Psychology: General,* **108,** 48–67.

Staddon, J. E. R. (Ed.). (1980). *Limits to action: The allocation of individual behavior.* New York: Academic Press.

Staddon, J. E. R. (1983). *Adaptive behavior and learning.* Cambridge: Cambridge University Press.

Staddon, J. E. R., & Hinson, J. M. (1983). Optimization: A result or a mechanism? *Science,* **221,** 976–977.

Sutton, R., & Barto, A. (1981). An adaptive network that constructs and uses an internal model of its environment. *Cognition and Brain Theory Quarterly,* **4,** 217–246.

Taylor, C. (1964). *The explanation of behaviour.* New York: Humanities Press.

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological Review,* **55,** 189–208.

von Neumann, J., & Morgenstern, O. (1944). *Theory of games and economic behavior.* Princeton, NJ: Princeton University Press.

Williams, B. A. (1990). Enduring problems for molecular accounts of operant behavior. *Journal of Experimental Psychology: Animal Behavior Processes,* **16,** 213–216.

Williams, B. A. (1991). Choice as a function of local versus molar reinforcement contingencies. *Journal of the Experimental Analysis of Behavior,* **56,** 455–473.

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